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Healing of Reconstructed Ligament Insertion

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Reconstructive surgery of insertions of ligament and tendons into the bone belongs to the most frequently carried out operations in reconstructive orthopaedic surgery.

The variety of techniques used can be reduced to two principally different procedures: tendon and ligament transplants can be either periosteally fixed or directly into the bone itself. Although both principles have been widely used for reconstruction of tendon and ligament insertions, there is controversy about the advantages of different methods of reinsertion (KERWEIN et al. 1938[4], JAGER and WIRTH 1978)[3]. Moreover, the biological and mechanical value of the different methods of reinsertion has not been proved experimentally yet.

In this study, four standard procedures for reconstruction of ligament insertions were therefore tested by means of animal experiments.

Material and Methods

The experiments were carried out on a total of 24 mature sheep. The animals were anaesthetized by application of Rompun 0, 1 ml/kg body weight+Ketavet 5 mg/kg body weight; under general anaesthesia both knee areas were shaped and cleaned. After skin desinfection and sterile draping, a longitudinal incision was made so that the ligamentum patellae was exposed and devided into three strands. In order to preserve the stretching ability of the knee the medial strand of the ligament was left as it was. In the right hind limb, the lateral portion of the ligament was sutured onto the periosteum of the tibia, whilst the medial section of the ligament was screwed into the head of the tibia under a lamella of bone. In the left hind limb, we laid the medial section of ligament under a periosteum bridge and sutured it onto the periosteum which lay behind it. The lateral section of the ligament was taken out of the insertion area together with a block of bone adhering to it and attached in a trans-tibial drill hole with the help

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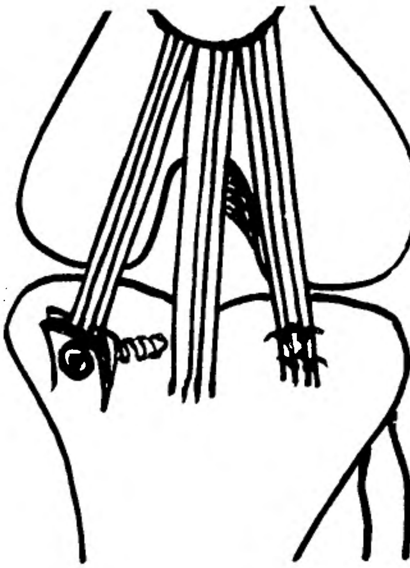


Fig. 1a. Reinsertion. Left hind limb.

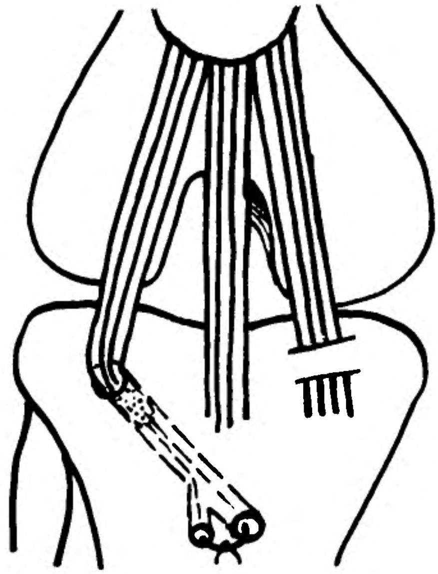


Fig. 1b. Reinsertion. Right hind limb.

of a thread (Fig. 1a, b). The position of the four various standard insertions had been determined beforehand on a knee-specimen by simulating the ligaments with threats so that the resulting elongation remained under 3% to provide overstretching.

The sheep stood up postoperatively as soon as the anaesthetic had worn off. Apart from a little stiffness in the knee joints for the first three days after the operation, the function was not impaired. The animals were kept in a pen for 14 days until wound-healing had been completed and then they were brought back to their flock where they grassed according to survival 6, 12, 24 and 40 weeks.

Results

Histological examinations:

For the histological investigations samples were taken from the insertion area and after histological preparation were examined under light and polarisation microscope.

A) Suture onto the Periosteum:

The samples of the 6-week series exhibit fibrous connective tissue of differing thickness with differing ingrowth of the fibres in the periosteum. This picture remains essentially the same after 12 weeks. After 24 weeks cartilagenous elements can be recognized which penetrate the ligament structure in finger-shaped form. Whilst the content of fibroblasts has decreased the content of fibres has significantly increased.

After 40 weeks, the picture impresses us because of its content of fibers which has increased further and also because of the low content of cells.

In the meantime, we can clearly recognize the four zone layering of the ligament insertion

Fig. 2a. Stitching onto the periosteum, six weeks postoperatively. Fibrous connective tissue with ingrowth of periosteal fibres (arrows) (Van Gieson, 50×)

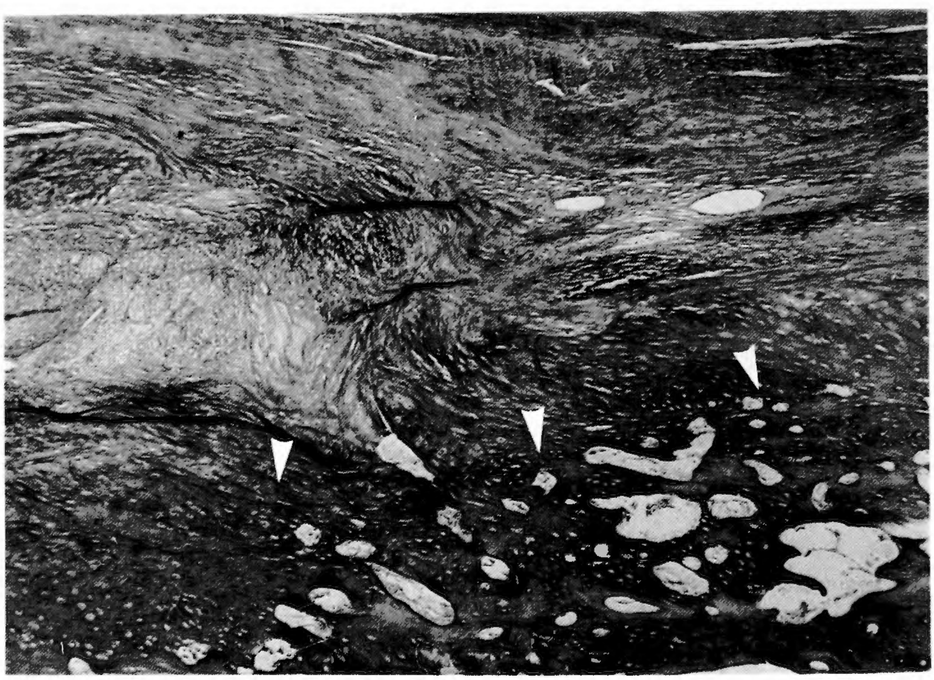


Fig. 2b. After 24 weeks, cartilagenous elements are appearing (arrows). (van Gieson, 50×)

with the free collagenous fibres, the fibres of the uncalcified layer of fibrocartilage, the calcified layer of fibrocartilage and finally the bone (Fig. 2a, b).

B) Screwing under the Lamella of Bone:

In the six week samples we can recognize a fine fibrous tissue which radiates into the bone and establishes a close connection to the bone. Edematous areas of swelling can be observed between cartilage and bone now and again. These are possibly results of small local necrosis (Fig. 3a, b). This picture also remains after 12 weeks.

After 24 weeks, a discreet, cartilagenous reaction can be observed. This is, however, no typical four zone formation yet.

After 40 weeks the samples show a considerable activation of fibrocartilage, which seems to be equally distributed. This results in the picture of a typical four zone formation of the ligament insertion (Fig. 3b).

C) Subperiosteal and Supraperiosteal Fixation:

The periosteal bridge is still clearly recognisable on the six week sample. Behind it, there are clusters of fibroblast activation. The surface of the bone under the periostal "bridge" seems to be stimulated and exhibits here ingrowth of fibres into the bone. At the end of the periosteal "bridge", we can recognize isolated centres of cartilage, which are even more easily recognized in the twelve-week samples.

After 24 weeks, a widespread fibre reaction can be seen. The fibrous tissue has a low content of cells. On the other hand, there is an even ribbon-formed distribution of cartilage areas (Fig. 4a).

After 40 weeks, the typical four zone formation has been completed: Ligament—uncalcified cartilage—calcified cartilage—bone (Fig. 4b).

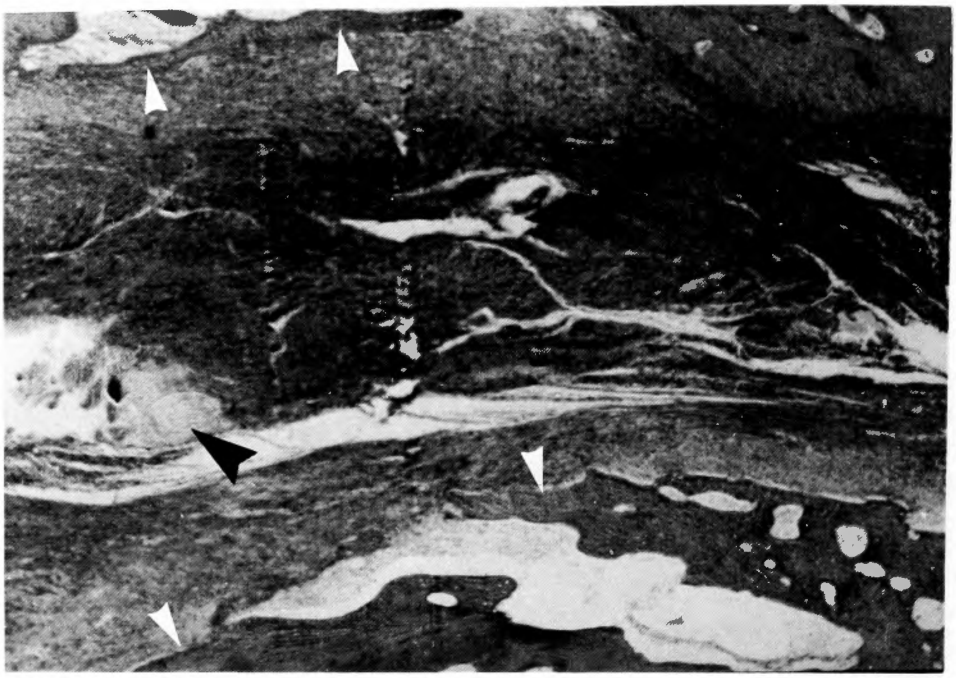
D) Insertion with Adhering Block of Bone in the Drill Hole:

Recognisable of the 6 weeks, even more so after 12 weeks, are considerable bone necrosis and phagocytic reactions of macrophages (Fig. 5). Besides this, we can also observe areas where the block of bone has grown onto the bone into which it has been inserted. This picture can also be observed after 24 weeks.

After 40 weeks, too, numerous centres of necrosis are clearly recognisable.

Biomechanical Experiments:

In order to examine the strength of different methods of insertion, we carried out biomechanical experiments. For this purpose, the middle strand of the ligamentum patellae was taken away. The medial and lateral strands were each prepared, so that they had almost the same diameter at the site of insertion into the bone. By means of a series of circumference measurements taken at a distance of 2 mm from each other, differences in diameter could be registered. After longitudinal osteotomy of the knee-cap, we had two Patella-Ligament-Tibia-samples respectively. The samples were fixed in a test machine and were drawn out until they broke away from the bone insertion at a tensile speed of 4.5 mm/min. The absolute strength



a. After 6 weeks, fine fibrous tissue radiates into the bone (white arrows). Small local necrosis can be seen (black arrow). (Van Gieson, 50×)

b. After 40 weeks, typical 4 zone formation has developed.
1. free fibres, 2. zone of unmineralized fibrocartilage, 3. zone of mineralized fibrocartilage, 4. bone (PAS, 50×)

Fig. 3. Screwing under a lamella of bone

a. Ribbon-formed distribution of cartilage areas (arrows). (Van Gieson, 100×)

b. Typical 4 zone formation, 40 weeks postoperatively.
1. free fibres, 2. zone of unminerlized fibrocartilage, 3. zone of mineralized fibrocartilage, 4. bone (PAS, 100×)

Fig. 4. Sub- and supraperiosteal fixation

Fig. 5. Insertion with adhering block of bone.
Six weeks postoperatively, bone necrosis and phagocytic reactions of macrophages can be observed (arrows) (Van Gieson, 50×)

of the samples could be determined on the force-way diagram and the cross section thus obtained. The physiological tensile strength of the samples were determined by the same experiments on a comparable series which had undergone no operation.

The tensile strength of those samples which had undergone screwing under a lamella of bone reached normal values after six weeks and from then on increased only very little. The tensile strength in the rest of the insertion models remains clearly under the physiological value after 6 weeks. Whilst the lower region of normal values is reached after 12 weeks in the sub- and supraperiosteal fixation, the insertion with an adhering block of bone in the drill hole does not reach comparatively normal values until 24 weeks. After this period of time, all three curves exhibit a steady increase to a value in the middle of the normal range (Fig. 6).

Discussion

The histological and biomechanical results of our experiments reveal that mechanical rigidity can be obtained most quickly by screwing the ligaments structures under a lamella of bone. This confirms the observation of Kerwein (1938). As a factor of risk, we regard in this method the amount of compression which is given to the fibre structures. If there is too little compression, the ligament structures can slip; if there is too much compression, necrosis of the ligament structures can occur.

We could observe this phenomenon histologically in two cases in this series. Stitching onto

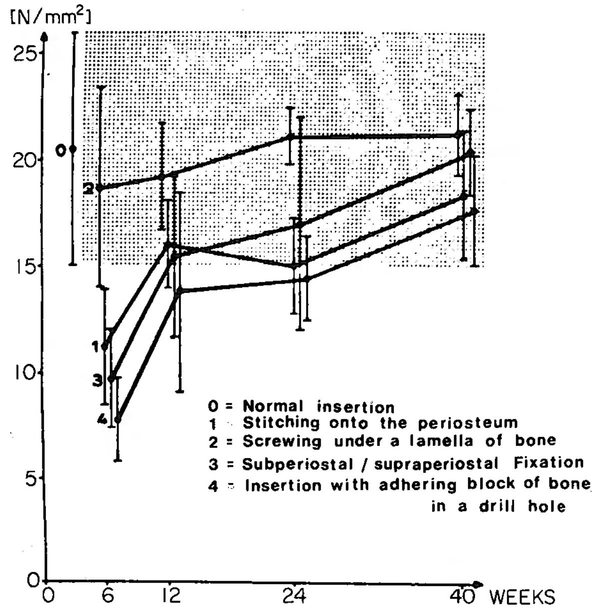


Fig. 6. Biomechanical study on tensile strength

the periosteum as well as sub- and supraperiosteal fixation reach the normal range of tensile strength only after approximately twelve weeks. From this time on, the sub- and supraperiosteal fixation shows a continous fast increase while stitching onto the periosteum improves its tensile strengths only very slowly. Prerequisit for the clinical use of these methods of periosteal reinsertion is a strong and thick periosteum which is suitable for suturing and can be utilized as a periosteal bridge.

Among the tested methods, the ligament reinsertion with an adhering block of bone in a drill hole showed the poorest results. Our histological examinations emphazise the observation of CHIROFF (1975)[2] that tight and firm fixation of the bone block in the drill hole is a definite requesit for an osseous healing of the bone block. If there is movement in this area, necrosis of bone with fibre remodeling lead to a pseudarthrosis and the tensile strength of this reinsertion increases then only very slowly. In clinical practice, tight filtring of the block of bone in the drill hole can be obtained by pressing an autogenous cancellous bone block into the drill hole (BURRI 1981)[1].

Conclusions

In every one of the experimental models, we were able to detect cartilagenous elements in the area of insertion after 24 weeks.

The biomechanical tensile strength experiments which were carried out simultaneously, resulted in all four insertion models having the same absolute tensile strength after 40 weeks.

The experimental models with sub- and supraperiosteal fixation as well as the experimental model with the screwing on under the lamella of bone exhibit the metaplastic change of the insertion area to the typical four zone formation due to the functional stimulus of weight-bearing.

The extensive necrosis in the insertion models with an adhering block of bone in the drill hole must be considered an artefact and is, according to our observation, due to an unstable position of the block of bone in the drill hole. In order to obtain the desired healing of the bone, a sure and stable position of the block of bone bearing the tendon or ligament insertion in the drill hole is necessary.

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和文抄録

靱帯付着部の再建に関する実験的研究

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靱帯や腱の付着部の再建術は整形外科領域において比較的よく行われる手術である．その術式としては断端部を骨膜に縫合したり，骨に直接固定したり，種々の方法が用いられているが，どの方法が組織学的，生体力学的に最も有用であるかはあまり検討されていない．本実験においては24頭の成熟羊の膝蓋靱帯を用いて以下の4方法の付着部の再建術を行い，それぞれの方法の効果について検討した．すなわち (1) 脛骨近位の骨膜上に縫合，(2) 脛骨近位部の下にねじ固定，(3) 骨膜橋の下を通して骨膜に縫合，(4) 骨・靱帯ブロックを骨孔を通して固定，の4方法を行った．術後6，12，24，40週で付着部の観察を行った．24週においては軟骨組織の増生がみられ，40週においては骨孔内を通して固定した例では骨壊死の所見が強く，層板骨下にねじ固定した例では組織学的・力学的に強固な靱帯付着部の4層構造の再生所見を示した．